# Acoustic Scattering Models of Zooplankton and Microstructure

Timothy K. Stanton
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
E-mail: tstanton@whoi.edu
Phone: (508) 289-2757; Fax: (508) 457-2194

Peter H. Wiebe
Department of Biology
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
E-mail: pwiebe@whoi.edu
Phone: (508) 289-2313

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## LONG TERM GOALS

To understand the acoustic reverberation properties of zooplankton and microstructure. The results will lead to improved capability in 1) predicting sonar performance and 2) use of sonars in the mapping of the zooplankton and microstructure.

## OBJECTIVES

To understand the physics of the scattering by naturally occurring (complex) bodies so that realistic acoustic scattering models of zooplankton and microstructure can be developed.

## APPROACH

The research is a balance of theoretical analysis, numerical simulations, and experimentation in the laboratory and local waters at WHOI. The theories are approximate and have included various ray, volume integration, and modal-series-based solutions. An acoustic pulse-echo laboratory is used to collect backscatter data off of the animals and turbulence over a wide range of acoustic frequencies (24 kHz to 1 MHz) and all angles of orientation (0 to 360 degrees in 1-degree steps). A high performance towed platform (BIOMAPER-II) is used to simultaneously collect acoustic backscatter data (transducers at five frequencies (43 kHz to 1 MHz) looking up and down), video data, and environmental data (temperature, etc.).

## WORK COMPLETED

A number of major tasks were completed this year involving various parallel efforts of theoretical, data analysis, and field work.

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1) PUBLICATIONS. In FY97, four peer-reviewed papers and a book chapter appeared in print and four new papers (for refereed journals) and a new book chapter were submitted. Also, we have synthesized much of our findings from many years of research in this area and submitted the work for publication in the form of a book manuscript. Four other peer-reviewed papers remain in press at the end of the fiscal year and six conference proceedings were submitted for publication.

2) PROCESSING OF DATA COLLECTED IN 1997 LABORATORY EXPERIMENTS ON IRREGULAR ELASTIC SHELLED (ANIMAL) BODIES. Last year, an extensive data set was collected in our laboratory of acoustic backscattering by various benthic elastic shelled animals (periwinkles) over a wide range of frequencies (24 kHz to 1 MHz) and over all angles of orientation in 1-degree increments. This year, the data were processed several ways in order to put it into analyzable form: target strength versus angle of orientation (at fixed size) for various frequencies, target strength versus angle of orientation (at fixed frequencies) for various sizes, target strength versus frequency at fixed size and orientation, and compressed pulse output versus time (at fixed size) for various angles of orientation.

3) ACOUSTIC SCATTERING MODELING OF IRREGULAR ELASTIC SHELLED (ANIMAL) BODY. Much of the physics of the scattering process was revealed in the above-mentioned data analysis. This allowed formulation of a scattering model for the animals. As a basis for the formulation, we used a model that we had previously developed for planktonic elastic shelled animals (gastropods) where a smaller set of data was available. This rich new set of data allowed us to more definitively determine the dominant scattering mechanisms and formulate a more general model which includes a class of ray not used in the previous model.

4) ACOUSTIC SCATTERING PREDICTIONS OF SHELL-COVERED SEAFLOOR. We incorporated the new model for benthic shelled animals into a simple rough interface scattering model. Estimates were made of the scattering of sound by a shell-covered seafloor and compared with data in the literature.

5) IN-SITU MEASUREMENTS OF TARGET STRENGTHS OF GAS-BEARING AND OTHER ZOOPLANKTON. We conducted at-sea measurements of target strengths of free-swimming zooplankton. The research was done by mounting our laboratory transducers onto a remotely operated vehicle (ROV) and driving the vehicle in scattering layers. The ROV allowed us to hover near an animal so that we could collect many echoes from the same individual while at the same time recording co-registered video data.

6) ACOUSTIC/OPTIC SURVEY OF A SHALLOW-WATER COASTAL REGION USING BIOMAPER-II. The first science cruise of the ONR/DURIP-funded BIOMAPER-II was conducted in October of 1997 (this cruise followed the test and evaluation cruise in July, 1997). A large area in the Gulf of Maine was surveyed. As part of the survey, an internal wave was located by use of the ship's radar and the wave was surveyed four times with the BIOMAPER-II. The system was towed twice while flying over the wave and once each through two different scattering layers in the wave.

7) DATA PROCESSING AND PRELIMINARY ANALYSIS OF ACOUSTIC/OPTIC SURVEY. The data from the ten acoustic transducers, video plankton recorder (VPR), and various other optical and environmental sensors have been processed for much of the cruise and internal wave. The

dependence of acoustic scattering upon acoustic frequency for each of the scattering layers has been determined.

## RESULTS

SCATTERING BY INDIVIDUAL ELASTIC-SHELLED BODIES. We now have a greatly improved understanding of the acoustic scattering by a certain class of elastic-shelled (animal) body. We have determined the importance and formulated a prediction of a class of wave (inside the opercular opening) not described in our earlier predictions. We have also been able to formulate a model that can predict, with reasonable accuracy, the acoustic scattering by these types of scatterers (averaged over size and orientation) over a wide range of acoustic frequencies (Rayleigh to geometric scattering). These results are important for predictions of scattering by both individuals and aggregations of shelled bodies.

SCATTERING BY SHELL-COVERED SEAFLOOR. Our acoustic scattering models based on the extensive data set allowed us to make predictions of the acoustic scattering by a shell-covered seafloor. These simplified first-order predictions were consistent (or nearly so) with data published in the literature and help to confirm the importance of the presence of shells in the scattering by the seafloor.

SCATTERING BY GAS-BEARING ZOOPLANKTON. In earlier work we showed that the scattering by gas-bearing zooplankton (siphonophores) in a laboratory tank produced significant echoes. However, we could only hypothesize on what the scattering levels could be in the natural environment and at deeper depths. These in situ target strengths of the free-swimming animals have shown that the echoes are also strong at the deeper depths and will help us to produce reliable field models of the scattering.

SCATTERING BY ZOOPLANKTON IN THE PRESENCE OF AN INTERNAL WAVE. The frequency dependences of the acoustic scattering by the two different layers in the internal wave were different from each other in a striking way. One dependence was consistent with scattering by zooplankton and the other dependence was consistent with scattering by turbulence. While the actual mechanisms are currently under investigation, it is clear that one must exercise caution in inferring what is causing the scattering. Also, without applying any analysis, another striking result was the fact that one of the waves was essentially acoustically transparent (i.e., undetectable) at the lowest frequency of 43 kHz while the other wave was barely detectable at the highest frequency of 420 kHz. This observation also demonstrates the care one must exercise in choosing the frequency or frequencies at which one uses to map internal waves and zooplankton.

## IMPACT/APPLICATIONS

The impact from these results is three-fold:

1) Through development of these models, as motivated by the zooplankton and microstructure applications, we have formulated analytical and experimental approaches for the description of the scattering of sound by bodies with complex shapes and material property compositions. The approaches are applicable to a wide range of body types (beyond the specific cases of zooplankton and microstructure). In addition to the successful application to zooplankton and microstructure they have, for example, been successfully applied to irregular metallic structures.

2)  The development of these scattering models has improved the accuracy of interpretation of acoustic surveys of zooplankton and microstructure as discussed in the papers recently published by us and being submitted by others.

3)  The research involving the benthic shelled animals can help make predictions of acoustic scattering by shell-covered seafloors more accurate.

## TRANSITIONS

1) Some of our acoustic scattering models have already been used by NUWC/Newport for performance predictions of one of their high frequency acoustics systems.

2) In addition, we have identified two types of zooplankton (siphonophores and pteropods) that have high enough target strengths and occur in sufficiently high numbers that they could interfere with the performance of certain high frequency acoustics systems.  By use of our zooplankton scattering models, we have already provided a plausible explanation for some anomalous ("false target") returns in MK48 ADCAP torpedo reverberation data collected by NUWC/Newport that could not be explained by predictions of scattering by the seafloor or sea surface.

3)  We have recently conducted high frequency acoustic and video surveys of the Gulf of Maine and observed high concentrations of the gas-bearing animals.  The upcoming analysis will give us information on the target strengths of these animals *at depth* which will help simulation personnel in the Navy make better predictions of sonar performance.

4)  We have observed a strong resonance-like feature in the scattering by one size  class of benthic elastic shelled bodies at 24 kHz.  Since certain regions of the seafloor are heavily populated by shelled bodies, this information will be useful to Navy sonar performance modelers for reverberation predictions.

## RELATED PROJECTS

1)  We have applied experimental methods and scattering models developed as well as equipment purchased under this grant toward at-sea laboratory experiments funded by NSF grant OCE-9201264.

2)  We have applied some of the scattering models developed under this grant to help in interpreting acoustic survey data collected over the Georges Bank (a shallow water coastal region).  The data were collected under NOAA grant NA16RC0515 as part of the US GLOBEC program.

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**PATENTS**

None